THE JAPANESE VOLCANO ASO AND ITS LARGE CALDERA[1]

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BRIEF DESCRIPTION

Aso-san is a volcano in the center of Kiushiu, Japan, within twenty-nine miles of the western, and forty-five miles of the eastern, coast of the island. It consists of a huge mound-shaped cone on the summit of which is sunk an oval bowl measuring about ten miles in width, fourteen miles in length, and 1,000 to 2,000 feet in depth, the bottom being some 1,500 feet above sea-level. Within this bowl a range of mountains, attaining an altitude above sea of 5,600 feet and overtopping the rim more than 2,000 feet, runs from east to west across its short diameter and divides it into 2 crescent-shaped basins. On the summit of this dividing range is a low modern cone with active

[1] Read before the Geological Society of Washington, January, 1907.

crater; and at the foot of the range on either side a fairly level plain stretches off to a steep mountain wall that surrounds the bowl. At only one point a break occurs in this wall. The central range is so high and broad, and so completely shuts off the inclosed plain on the south from the one on the north, that one does not at once recognize the two plains as parts of a single great oval floor. But each of the basins is so perfectly the complement of the other that little doubt can exist of their being the two halves of a large crateral depression partitioned off by mountains of subsequent growth. The bowl has a typical caldera form, and it has most probably originated through the subsidence of a formerly overlying mountain mass. It is one of the very largest, if not the largest, of the craters known on this planet, and without doubt the largest having such perfect preservation.

SOURCES OF INFORMATION

The observations upon which this article are based were made in the spring of 1905, when I made a visit to the volcano and lived for nearly two weeks within the caldera.[1]

Little has been known or published concerning Aso-san. John Milne many years ago made a hasty visit to it and published a narrative and descriptive article in the *Popular Science Review*.[2] He has also discussed the history of the eruptions of the new crater and noted other features of the volcano in the *Transactions of the Seismological Society of Japan*.[3] Aso-san is briefly described by Edmund Naumann in his paper "Ueber den Bau und die Entstehung der japanischen Inseln,"[4] and there is an article in Japanese on the subject in the Tokio *Journal of Geography*, written by T. Iki.[5]

No detailed maps are available upon which to base statements regarding Aso. The altitudes and other measurements here given are approximate but are based on careful estimates, on barometric measurements, and on general maps of Kiushiu. The accompany-

[1] In company with my brother, Malcolm Anderson, and friend, Kiyoshi Kanai, to both of whom I am indebted for photographs and information.

[2] New Series, Vol. IV, No. 16, October, 1880.

[3] Vol. IX, Pt. II, 1886.

[4] Berlin, R. Friedländer & Sohn, 1885.

[5] Published by the Tokio Geog. Soc.; Vol. XIII, No. 149, April, 1901.

ing diagram is largely from memory and is intended merely to convey a general idea of the caldera.

GEOLOGY OF KIUSHIU

The island Kiushiu, which covers about 17,000 square miles, has a foundation of rocks of Paleozoic age and possibly some belonging to the Archaean. These are largely sedimentary, and frequently metamorphic; but associated with them are many varieties of igneous rocks. Less altered strata of supposed Mesozoic age, but possibly

FIG. 1.—Sakura-jima, an andesitic cone of medium slope, in the bay of Kagoshima at the southern end of Kiushiu. Its last eruption was in 1779. Its altitude is 3,850 feet.

in part representative of the early Tertiary, overlie these extensively; and fossiliferous, much-disturbed Tertiary formations occur in numerous relatively small detached basins. Over these basement rocks a superstructure of eruptives has been built up during the Quaternary, having probably been begun before the close of Tertiary time. About one-half of the island is now covered by these volcanic rocks. In some places the covering has the nature of a thin layer of ash or volcanic mud or lava over the old surface, whereas in others it has a great thickness. The whole of the north-central part of the

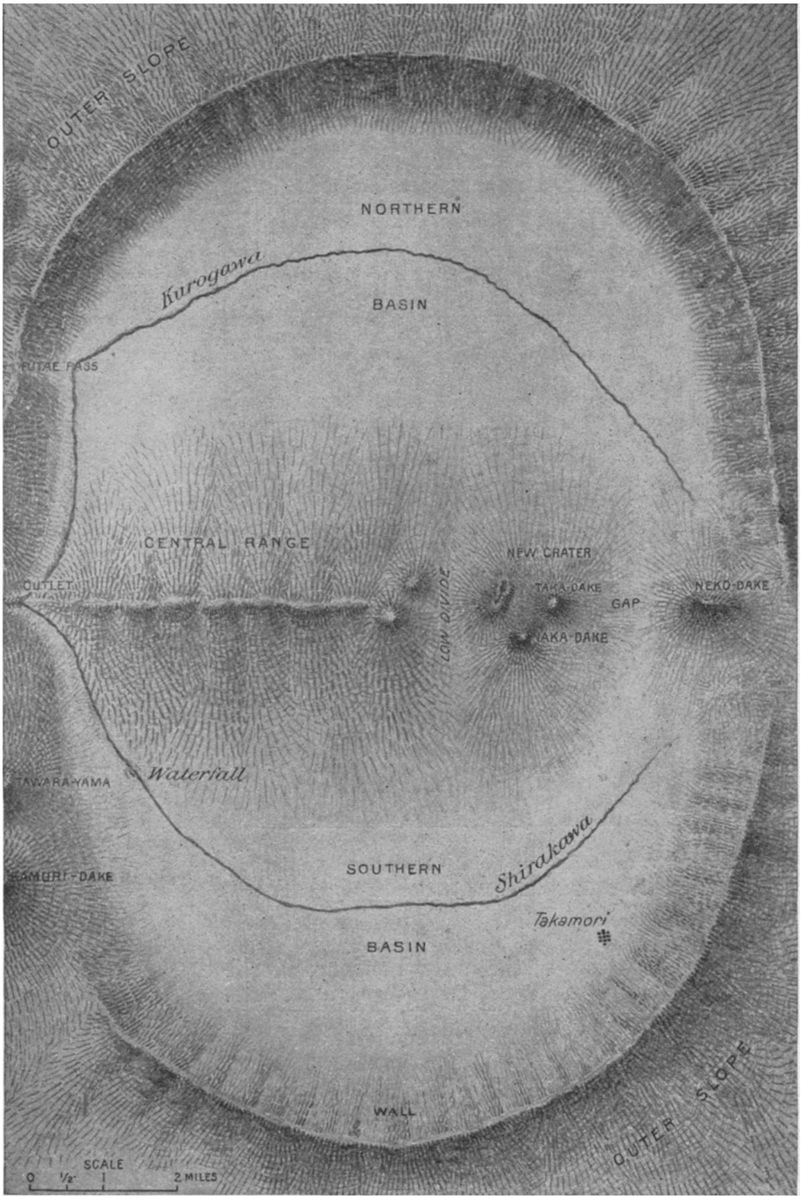

FIG. 2.—Rough diagram of the Aso caldera.

island and much of the southern part is volcanic. The Japanese geologists count twenty volcanoes in Kiushiu, including two that form small islands near the coast on the south. The period of volcanic construction extends into the present—eight of the twenty volcanoes being still living—but the general activity seems to be on the decline. The volcanic forces must have reached their climax sometime during the middle Quaternary, to judge from the amount of erosion that has taken place since the greatest outpourings occurred; and it is probably from this period that the long since extinct crater of Aso dates. In its prime Aso doubtless held a position of pre-eminence among the volcanoes and mountains of Kiushiu, as is indicated by the extent of territory that is covered by material derived from its eruptions, and by the grandeur of the scale upon which the crater was built and the probability that a cone formerly rose to a great height above it. Its present peaks are surpassed by a few others in the island, the highest of which is the non-volcanic mountain Sobo-san, 6,600 feet in altitude.

APPROACH TO THE CALDERA

Aso-san may be most easily reached from Kumamoto, a city situated on the coastal plain near the western coast of Kiushiu. From there a road runs up into the mountains and down into the caldera, which is about twenty miles away. The volcano does not form a prominent cone as seen from this side and appears merely as a high portion of the mountain mass that occupies the island's interior. The caldera becomes apparent only on an approach to its very edge, or from the summit of one of the high mountains within a score of miles of Aso. From such a summit one looks down upon it and obtains an impressive view of the huge bowl and the high volcanic peaks that spring from within it.

THE FLOOR

Viewed broadly, the floors of the two basins into which the caldera is divided are level plains lying at the same elevation. They slope gently upward from west to east. On the east they break into low sweeping ridges and knolls that rise gradually and merge with the wall and central range, which are there convergent. (See Fig. 3). Throughout the centra portion of each of the two basins the floor

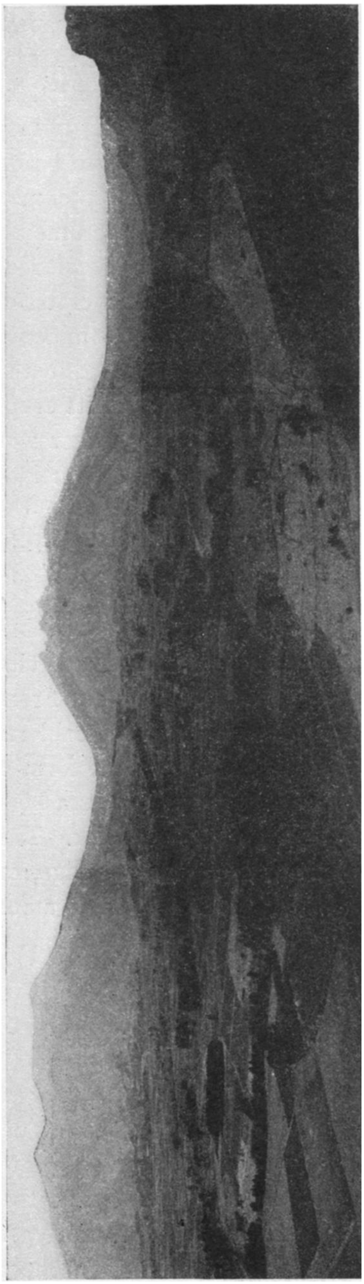

FIG. 3.—Panorama of the southeastern portion of the caldera. Looking north and northeast from near Takamori. Naka-dake and Taka-dake on the left, Nekodake in the center, and the ring wall on the right. Photo by Malcolm Anderson.

except for gentle undulations, is almost level and has an average elevation of about 1,500 feet. On the inner side of each it slopes gently up to the central range, and on the outer side to the wall. Each half of the caldera is traversed by a stream that follows a shallow curving course from east to west. The stream in the southern basin is called "Shirakawa" (*kawa* or *gawa* means river); that in the northern, the "Kurogawa." The usually dry, branching, tributary runnels in the upper course of the former are shown in the middle foreground of Fig. 3. The Kurogawa carries considerably more water than the former and is worthy to be called a small river. (See Fig. 5.) These streams unite around the western end of the central range, which just fails to reach the wall there, and flow out through a canyon or barranco. The single stream thus formed, called the Shirakawa, runs westward down the mountains and across the Kumamoto plain to the sea. The point of outlet is at an elevation of about 1,000 feet above the sea, and on approaching it the streams leave their gentle

course over the comparatively flat plain and tumble down to their junction at the outlet with gradients of 4 to 8 per cent. or more. The northern one makes the descent the more rapidly. The southern one on leaving the upper level of the floor drops over a picturesque waterfall.

The northern basin appears to be larger and rounder than the southern one and its floor is even more level. Small parts of it were

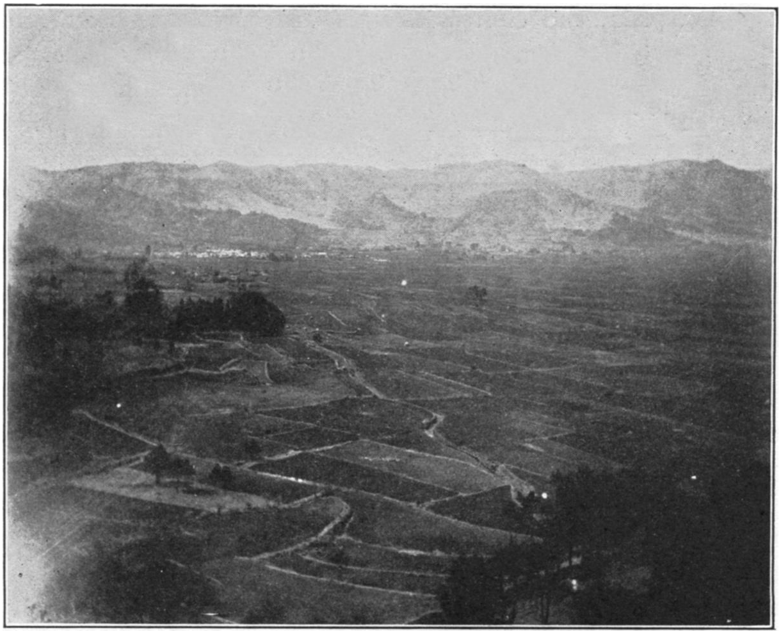

FIG. 4.—A portion of the ring wall, looking southwest across the cultivated floor of the southern basin. The wall in this portion is considerably worn. The town of Takamori shows in the distance on the left. Photo by Malcolm Anderson.

flooded or marshy during April, 1905. Several small isolated and fairly steep hills rise out of the northern basin. They were not observed closely but looked as if they were composed of the same material as the wall.

The surface deposits of the floor appear to be chiefly fine sandy material and coarse yellow sand and gravel in horizontal layers, covered with black, slightly sandy soil. The deposits were probably

formed by a mingling of the products of eruptions and erosion. The low slopes and hillocks where the plain rises into the wall are, as far as observed, composed of lava both vesicular and compact, and it is most likely that the floor within no great depth below the surface is composed of the same material.

The floor of the caldera is everywhere cultivated, and supports a population that may be roughly estimated as amounting to at least 5,000 people. Many villages and groups of dwellings are scattered over the plain, and clusters of trees stand here and there. The whole scene is a remarkable one, being especially brilliant when the spring crops, which consist chiefly of green wheat and mustard with yellow flowers are maturing. There is a legend that the mountain-girt bowl of Aso was once occupied by a lake, until the god of the mountain kicked a hole in the wall where the present outlet is and allowed the water to flow out. There may have been in former times flooded areas of more wide extent than those noted above, but it does not seem probable that a real lake ever occupied the caldera.

THE WALL

The caldera has an oval shape and its rim forms a smooth sweeping curve around the whole circumference, broken only at the cleft on the west where the streams pass out, and on the east where the wall is joined by the descending slope forming the extremity of the central range. The curvature of the wall is so slight that it appears at a glance like the face of a straight mountain range. On the basis of a rough estimate it may be said that the average slope from the floor to the top of the wall would nowhere exceed 25 or 30°, although rocky almost vertical precipices occur at points on its face. The wall is furrowed by gulches that have in places eaten back to the summit and notched the skyline of the rim. In general, however, its top is fairly even. Between the gulches sharp ridges run out into the floor. The wall varies in appearance from point to point, and the ridges and prominences on its face have a variety of picturesque shapes. The wall of the southern basin, exposed to the north, is much more worn than that of the northern one. Forms resembling the remains of terraces appear in places. The lower portion of the wall has a gentle slope, and at some places is deeply soil-covered

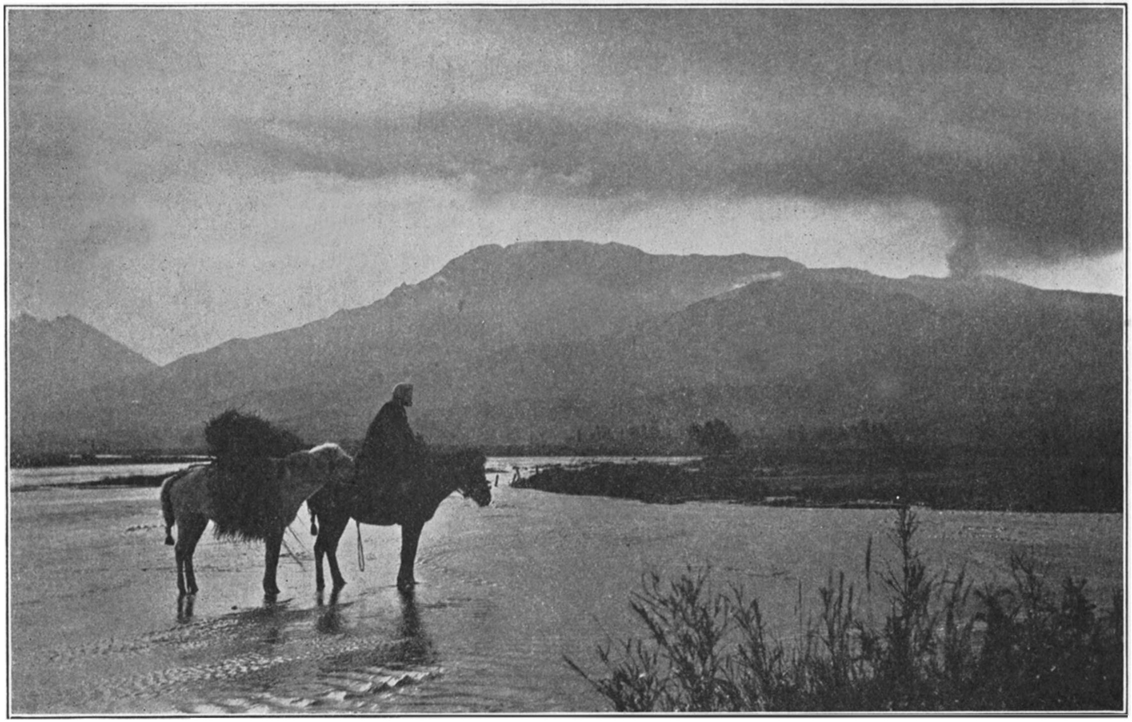

FIG. 5.—The central range from the floor of the northern basin. In the foreground flows the Kurogawa; on the right a vapor cloud rises from the modern crater; in the center is Taka-dake, 4,000 feet above the foreground; and on the left is a portion of Neko-dake. Looking southeast.

and supports a fine grove of trees. The higher portion is precipitous and exposes best the material of which it is made. It is formed of roughly bedded flows of basaltic andesite, interbedded and intermingled with mixtures of vesicular lava, scoriae, pumice, and volcanic sand. The lava predominates, and the harder layers project with vertical rocky faces, while between them softer zones have weathered way into débris slopes. The height of the wall is on the average about 1,300 to 1,500 feet. It decreases toward the eastern side owing to the gradual rise of the floor in that direction, but increases at some points, as on the southwest and west sides, where mountains break the regularity of the horizon line.

The only opening in the ring wall is the barranco on the eastern side through which the streams have their outlet. Cliffs of roughly columnar lava form the sides of this gorge up to a height of several hundred feet and are continued upward by densely wooded slopes that rise over 1,500 feet above the stream bed. The span of the canyon where it begins to widen out above the cliffs is less than half a mile.

Probably the next lowest point upon the rim is at a point three miles north of the outlet, where the "Futaetoge" (*toge* means "pass"), which has an elevation of about 2,500 feet above the sea, is less than 1,000 feet above the caldera floor. Another stream running down the outer slope to the sea heads at this low point. The highest portion of the watershed on the rim is on Tawara-yama and Kamuri-dake, two mountains that form the wall at the western end of the southern basin. They rise 2,000 to 2,700 above the floor of the caldera. The former is between two and three miles south of the outlet of the streams, the latter four miles or more. The summit of each and the high ridge connecting them is about two miles back from the floor.

THE CENTRAL RANGE

The ridge or range that divides the caldera is, properly speaking, Mount Aso. From the floor on the south, or the one on the north, it appears as a massive rugged barrier the summit of which is roughened by several dominating peaks. (See Figs. 3 and 5.) Looking up at it from either basin one would never imagine the existence of a second and almost identical pit with level floor and encircling outer wall at

its base on the opposite side. It is only from one of the peaks in the range or from a distant mountain top that a conception of the whole as a unit and as a single vast caldera may be obtained.

There are three main peaks, all along the eastern half of the range. The western end is lower, has less bold outlines, and declines gradually toward the west. The most striking of the peaks in the range is Neko-dake at the very eastern end. (The word *dake* which forms

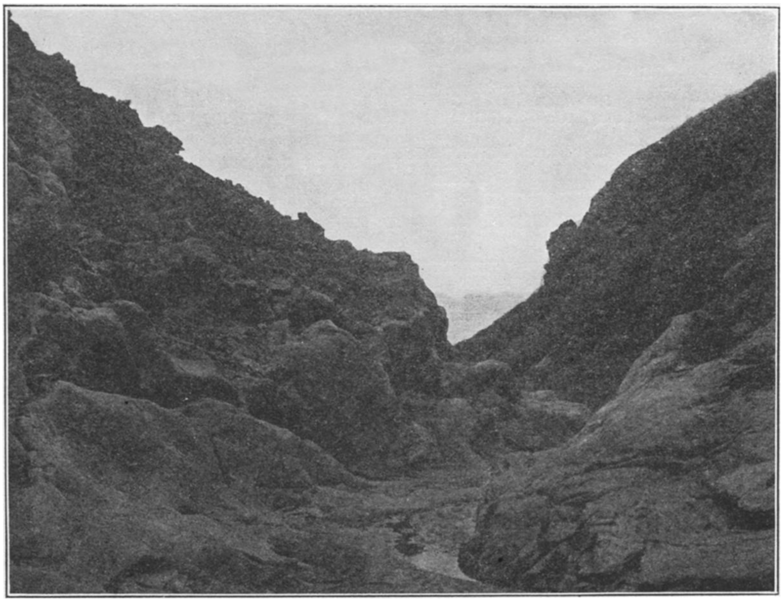

FIG. 6.—Recent-looking lava with smooth flow structure, high on the south side of Naka-dake. Looking south toward the southern wall, which shows dimly far across the caldera.

part of the name of many Japanese mountains means "peak.") Its slopes have the graceful curving outlines characteristic of volcanic cones and its summit is serrated with pinnacles of lava. Its eastern flank drops down and ends the range by merging with the outer wall. There is no sign of any continuation of the range beyond into the outer region, it being distinctly a line of peaks belonging inside of the caldera. The slopes of Neko-dake are steep, being in the main 25 to 30 degrees. A part of the summit is easily accessible, but the

highest point cannot be reached as it is an isolated monument of andesitic lava 100 feet high and having slopes of from 60 to 75 degrees on its sides.

The western flank of Neko-dake extends down most of the way to the crater floor, forming a depression in the central ridge 2,000 to 2,500 feet deep, so that the peak is left as an isolated pyramid with truncated, broken summit. The top is 4,800 feet above the level of the sea, and not much over 2,500 feet above the highest portion of the floor.

Beyond the gap just mentioned the central ridge continues westward and rises immediately into Taka-dake, the highest peak of all. It has an elevation of 5,600 feet, and rises some 4,000 feet above the plain at its base. The next peak, Naka-dake, is a somewhat lower one, on the southwest flank of Taka-dake, slightly out of line with the general east and west summit line of the ridge. Its shape is somewhat like that of a half dome, and it presents on the south side of its summit a broken precipice of black lava.

At the western base of the last two peaks the modern crater is situated, at an altitude of about 4,000 feet above the sea. The range declines still more just west of this, forming a depression in its central portion. (See left of Fig. 3 and right of Fig. 5.) This depression is by no means as low, however, as the one between Neko-dake and Taka-dake, and does not tend to break the continuity of the range as that one does. The surface of the range here is a wide upland covered with curious small steep mounds of volcanic débris.

The north and south flanks of the range sweep down with concave slopes into the wide level floor. They are furrowed by sharp ravines and intervening ridges that gradually lose their prominence among the gentler slopes toward the base. The slopes are not usually very steep, and are for the most part covered with soil and long grass. They afford little water, and are uncultivated and uninhabited.

Basaltic andesite of varying compact, cystalline and scoriaceous texture is the chief material of which the central ridge is built up. In the vicinity of the higher peaks exposures of lava are very prominent Over the lower, more gentle slopes, outcrops are infrequent. Deposits of ashes and pumice are scattered far and wide.

THE MODERN CRATER

The cone upon which the modern crater of Aso is situated has a slope of about 15 degrees and is only a couple of hundred feet high.

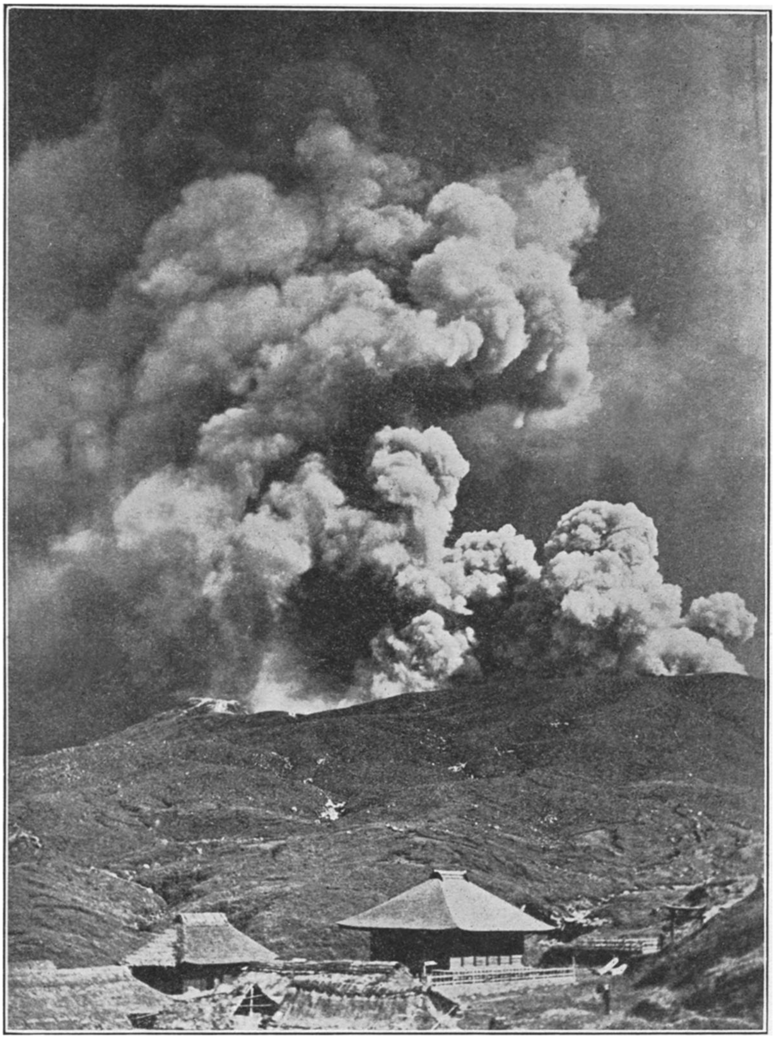

FIG. 7 —The modern Tuff cone on the summit of the central range, after a rain; looking northeast. The vapors issue from the northern end of the new crater. Young drainage lines are forming in the soft mud and cinders. In the foreground is a temple to the god Aso.

(See Fig. 7.) The cone is largely composed of fine-grained gray mud, which on drying becomes compacted into tuff. It is irregularly interbedded with lava and coarse fragmentary matter. This modern center of the activity of Aso is about one mile nearer the eastern than the western side of the old outer crater, but its position is roughly central with respect to the whole great oval.

The new crater is a black, ragged pit, constantly roaring and steaming. (See Figs. 8 and 9.) It has sheer walls of roughly stratified mud, the layers of which appear to dip inward, and a depth of three hundred feet or more. It is oblong in shape, and is at a rough estimate nine hundred feet across from east to west and two thousand feet long from north to south, the long axis being in the same direction as that of the outer crater. Its rim is very uneven, being much higher on the north and east than on the other sides. It is divided into five compartments or vents arranged along the long axis, each separated from the next by a steep wall of mud one hundred feet or more high. The two most northerly vents are the deepest and the only active ones. Occasionally when the vapor column diminishes one can look to the bottom of the northern vent and see the burning sulphur that plasters the lower walls and floor. The bottom is a round flat disk of cracked mud looking like the dried bottom of a pond, and there is no appearance of a hole or conduit descending to greater depths. The one next south of it is deeper and pours forth the most steam. No glimpse of its bottom could be obtained by the writer from any point upon the rim. The existence of activity in a decadent stage is indicated at other points, all in the western half of the Aso range, by jets of steam and hot springs. (See Fig. 11.)

DOUBLE RIM OF THE NEW CRATER

An interesting feature of the modern cone is a small ridge of mud that circles around the western side of the summit at a distance of about one hundred feet from the crater's edge. On climbing the cone one reaches what appears to be the summit only to find that one must descend some twenty feet into a moat and rise again a similar amount before reaching the lip of the crater. The moat acts as a line of drainage and carries the rain water southward along the summit of the cone, parallel with its long axis, to an outlet down the

mountains. On the east side there is no similar moat but the crater borders the cliffs at the foot of the peaks Taka and Naka and is separated from them by a stream channel, as shown in Fig. 10. A small double rim and moat was observed by the writer in the loose cinders for part of the way around the crater at the summit of Vesuvius in September, 1905.

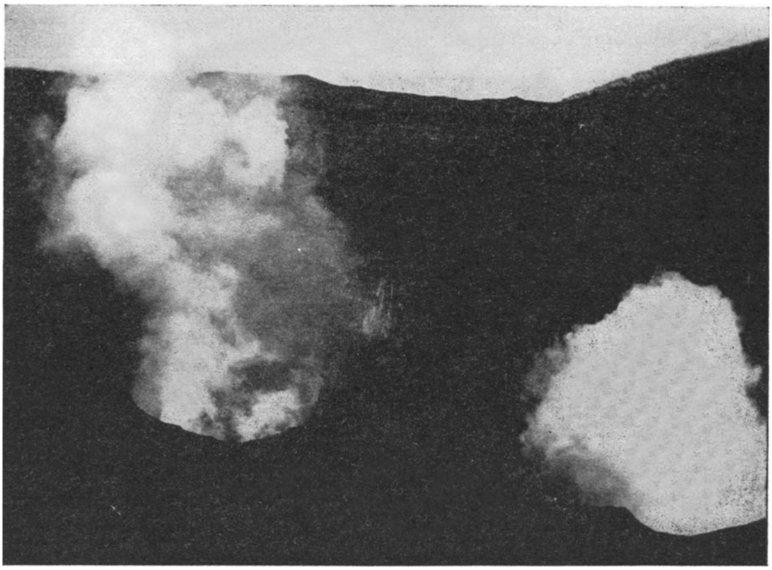

FIG. 8.—Looking northeast into the modern crater of Aso, showing the two most northerly vents and the stratified wall. These are the only active vents, the one on the right being more active and deeper. Photo by Malcolm Anderson.

HISTORY OF THE NEW CRATER

Aso-san has been in continual activity during the historical period. A detailed account of its history has been compiled by John Milne from interesting contemporaneous Japanese records.[1]

The greatest eruptions of very recent times were in the winter of 1873–74, when unusual activity continued during several months and ashes covered the ground to a distance of eighteen miles; in the winter of 1884 when ashes were blown over Kumamoto, making it so dark there at a distance of twenty-five miles that lamps had to be

[1] *Transactions of the Seismological Society of Japan*, Vol. IX, Pt. II, 1886.

used for three days; in 1889 during the year of the Kumamoto earthquake, which was the year following the great explosions of Bandai-san in central Japan; and lastly in 1894, when the floor of the modern crater was somewhat altered.

THE OUTER SLOPES

The vast open bowl of Aso occupies the summit of a great mound, the flanks of which, sloping gently away from the top of the interior wall, form a rolling hilly upland of low relief among the mountains of Kiushiu. This low dome-shaped mountain taken as a whole occupies at least 450 square miles. From above, the outer slope appears as an inclined plateau wrinkled with knolls and ridges and little valleys. All of these hillocks are of similar height, and destruction through erosion has not gone far. The general angle of slope away from the edge of the caldera is about 3 to 5°, but it is even less than this in places. On the northwest side it is very slight, because the flanks of the mound, which reach so far in other directions, there give place to a plateau between the rim and the not far distant volcanic mountains Kura-take and Ona-take. Within five to ten miles of the rim on most sides, at an elevation above the sea about the same as that of the bottom of the caldera, the outer slopes reach the foot of high mountains that almost completely encircle the upland, much as the caldera wall surrounds the plain formed by its floor. The surrounding mountain barrier is not volcanic on the east and south, where ancient sedimentary and igneous rocks form Sobo-san and other prominent peaks. The whole volcanic mass of Aso and of the mountains to the north is of the nature of a filling within a depression in the topography of the older formations.

The surface material of the outer slopes is largely fragmental débris. At a few places where it was observed exposed it appeared as massive deposits of sandy material, or as soft tuff, or as agglomerate composed of coarser fragments. Some of the hills many miles from Aso are entirely composed of fragmental volcanic deposits of this kind. Lava is frequently exposed on the western slope down to the Kumamoto plain; and in the upland region about Aso, toward the foot of the surrounding mountains, where dissection has advanced farthest, lava is much in evidence. It is most probable that

lava predominates beneath the surface throughout this whole region.

RADIATING LAVA FLOWS

Some miles to the south and east of Aso-san the surface covering of volcanic ejectamenta which has filled up and blotted out the ancient features of the landscape in this portion of Kiushiu ceases to be a solid sheet, and the underlying older formations come to light. But beyond

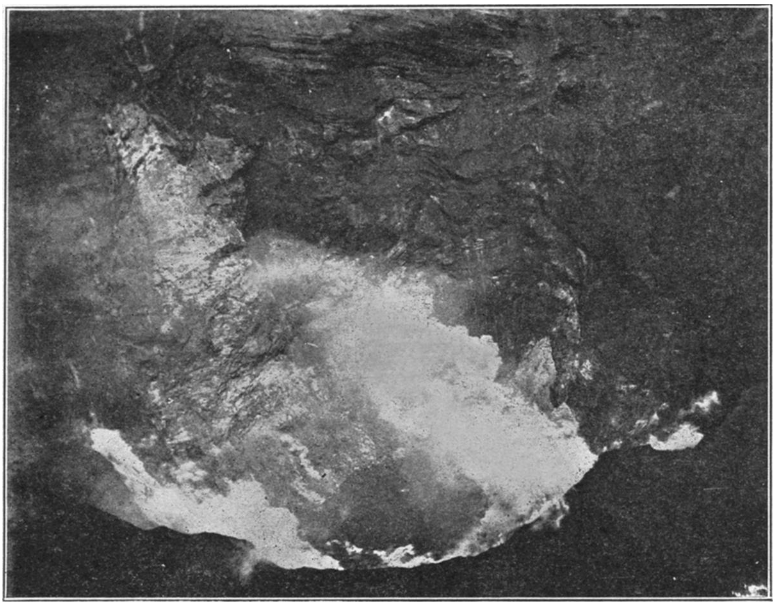

FIG. 9.—Looking down into the northernmost vent of the modern crater, showing the bottom and the sharp ridge of mud on the right between this and the next vent. The vapor comes chiefly from burning sulphur. Taken from the rim on the west side. Photo by Malcolm Anderson.

the line of contact, lava streams continue for great distances, partly burying the old river channels that radiate away from the region occupied by Aso-san, this region being the source of most of the large rivers of the island. Aso has evidently been the center of the volcanic activity of central Kiushiu and the source of supply of the erupted material mantling the region. The longest of the lava arms extends down the Gokase-gawa southeast of Aso, and was followed

by the writer to its termination on the east coast. The contact of the volcanic sheet and the older rocks in that direction is about twenty miles from the center of Aso, beyond which the lava extends down the canyon about thirty miles, almost to the sea. The width of the present lava filling of the canyon is on the average two and one-half to three miles, and the depth amounts certainly to several hundred feet. Nearly twenty-five miles away from the center of Aso the Gokase is joined by another large canyon from the north that issues from mountains in the Paleozoic formation. The lava flowed up this canyon for a distance of at least eight miles, filling its bottom likewise with a wide, deep stream. The source of the lava in this branch was the main stream that occupied the Gokase canyon. It could not have come down as a tributary flow because no volcanoes exist anywhere about.

High mountains formed of Paleozoic rocks inclose the valley of the Gokase-gawa, rising steeply above the fairly flat surface of the lava filling. In the center of this the river has cut an abrupt square canyon, and has already reached a depth of several hundred feet without coming to the level of its old course. The depth of the channel is at least three hundred feet in some places and its width is hardly more. Its sides are cliffs of basalt-andesite, usually with imperfect columnar structure. The columns, which average a foot or more in thickness, are sometimes four-sided, sometimes five-sided, the sides and angles being of irregular dimensions. They stand in the main perpendicular, but locally show deflections of a few degrees from this attitude.

CHARACTER OF THE LAVA

In the field the lava of the interior range, the ring wall and the surrounding region appeared to be the same. The rock is intermediate between andesite and basalt. That it is by no means of the most basic composition is indicated by the angle of the slopes presented in the interior range, and by the fact that explosive eruptions, with the ejection of abundant ashes and scoriae, have taken place in association with effusive eruptions throughout the history of the volcano. On the other hand, the recent-looking flows observable on the higher portion of the central range exhibit a smooth flow structure that is evidence of considerable fluidity and a prolonged state of fusion.

Three samples of lava from Aso were examined by Dr. Albert Johannsen of the U. S. Geological Survey, and the following description of these is based on the report which he kindly furnished. Specimen 1 is hypersthene-bearing basalt from the foot of the wall of the caldera near the town of Takamori on the south-east side. It is medium gray in color, compact, and highly porphyritic. The phenocrysts are about 55 to 60 per cent. labradorite, about 10 per cent.

FIG. 10.—Stream channel on the east side of the modern cone. The lip of the crater is immediately on the right, and the cliffs at the foot of the highest Aso peaks on the left. The fine gray mud is fast eroded by rains. Looking south, parallel to the long axis of the crater. Photo by Malcolm Anderson.

augite, and the rest hypersthene, magnetite, and olivine in decreasingly lesser amounts. The groundmass is made up of plagioclase, augite, and magnetite, with possibly a little glass. Specimen 2 is basalt from the same locality. It is mottled black and white, is somewhat vesicular, highly porphyritic, and strongly resembles specimen 1, especially under the microscope. The phenocrysts are about 80 per cent. labradorite, 15 per cent. augite, and the rest hornblende, magnetite, and olivine in decreasingly smaller amounts. The ground-

mass contains plagioclase, brown glass, magnetite, augite, and possibly a little olivine. Specimen 3 is a very vesicular fragment of hypersthene andesite blown from the new crater. It is composed of phenocrysts —labradorite and hypersthene in a groundmass of brown glass. Regarding these specimens Doctor Johannsen says as follows: "At best the amount of olivine in any of the rocks is slight, and with its absence I would name them all andesite."

A SUPPOSED FORMER MT. ASO

The roughly bedded strata in the walls of the big crater seem to dip away on all sides at a low angle, and their inclination is probably reflected in the gentle outer slopes that form the sides of the mound or cone of Aso. It seems likely that this mound is the basal remnant of a conical volcano that once continued upward to a culminating point high above the center of what is now the crater bowl.

If such a mountain existed it is probable that its upper portion rose with a gradually increasing slope into a summit cone. Judging from the character of the lava and the analogy afforded by the steep slopes of the present interior peaks of Aso, which seem to be constructed of materials similar to those of the wall, as well as by other volcanoes of Kiushiu (see Fig. 1), which are mostly built of similar andesitic lava and its fragmental products, the ancient cone may have risen in its upper portion even as steeply as 20° or 30°. But assuming that it rose with a constant slope no greater than now in places exhibited in the base, say 7°, its summit would have been over 7,000 feet in altitude above the sea. If it steepened above it may have been 10,000 feet or much more.

The amount of rock material that must have been removed to cause the disappearance of the whole upper portion of the cone and the opening of a wide bowl upon its site may be roughly estimated as at least fifty-four cubic miles, counting the volume of the caldera as twenty-five cubic miles—not subtracting the interior range—and the volume of the overlying cone as twenty-nine cubic miles.[1] If the cone rose steeply above, as it probably did, the volume must have been considerably more.

[1] The figures printed in the article by the writer in the *Popular Science Monthly*, Vol. LXXI, July, 1907, are incorrect.

ORIGIN OF THE CALDERA

There are three ways in which the old crater may be conceived as having originated, namely, by being built up around a vent of great magnitude, by the explosive removal of a volcanic mountain mass, or by the subsidence of the area now inclosed within the wall.

The most acceptable conclusion is that the bowl of Aso is a caldera produced by the sinking in of a volcano, as the result of the escape of

FIG. 11.—Hot springs at Yunotani near the western end of the central range. There is said to be a small geyser here that spouts out boiling water and red mud.

lava from an underlying reservoir at low points of discharge and the consequent undermining of the mountain flanks. The process was probably one of the gradual enlargement of an original summit crater.

There are three main reasons why this supposition seems to apply. In the first place, the bowl has a wide extent of almost level floor, a symmetrical oval shape, and a practically continuous ring wall of regular form. It is difficult to conceive of a violent explosion destroy-

ing the whole upper part of a mountain of such size and leaving such regular remains, whereas they might well be the outcome of a comparatively gentle process of sinking taking place simultaneously at all points around a common center. In the second place, the great lava flows radiating from the volcano are the quantitative equivalent of the mass that has disappeared from the old cone of Mount Aso, and may be reasonably considered as derived from the space in which the mountain became engulfed, having vacated this space through channels that opened at low points on the flanks of the cone. In the third place, the lava, although it is not of the most fusible variety, is of such a character that it would be capable of forming large, easily flowing and slowly cooling streams; and would not be of such viscosity as to offer the utmost resistance to explosive forces and to cause explosions of the greatest magnitude.

As regards the possibility of an explosive origin for the crater, it is to be expected that a prominent rim of débris would have accumulated around the brink of the cavity had such an immense block of the earth's surface been removed in this manner. Although it is true that a vast amount of fragmental material is present in the wide region surrounding Aso-san, no such rim is to be found. The balance of probability favors the conclusion that upward discharges of material did not play a chief part in excavating the bowl, but that the masses of ejectmenta covering much of the region around the volcano were thrown out partly before the destruction of the ancient mountain and partly during the period in which the process of engulfment was progressing, as a secondary phenomenon attending that catastrophe. The strata in the wall tell of explosive eruptions that took place contemporaneously with the emission of lava streams in the early history of the volcano, but it appears that the erupted material was chiefly in the form of lava flows. On the other hand, the decadent stages of the volcano have been marked chiefly by explosive eruptions as witnessed by the new cone and the deposits in its vicinity, and by the historical accounts.

As regards the other hypothetical mode of origin, the low cone of Aso may be thought of as having been formed by a process of cone building, through the overflowing of lava from a very large vent and the accumulation round about of material explosively removed.

But it is scarcely conceivable that a process alone of building up could have produced such forms as those of Aso.

John Milne discusses the origin of the Aso crater in the account of his visit to it before mentioned.[1] He considers unfavorably the theory of an explosive origin and comes to the following conclusion:

> I should be inclined to look upon it as being now, as it ever was, the upper crater of an old volcano, inside which in more recent times a cone has grown. Although at the commencement of the mountain the action may have been cataclysmic in its nature, subsequently, however, I should think that it grew up higher, partly by the accumulation of ashes, but now perhaps by the boiling over of a highly liquid trachytic lava. That this latter action has taken place seems to be testified by the roughly stratified appearances which are exhibited in the ring walls; the growth has in fact been probably something like the growth of Mauna Loa in the Sandwich Islands or as a geyser tube in Iceland.

ORIGIN OF THE CENTRAL RANGE

The theory of a subsequent origin for the interior range is the only acceptable one. The caldera may have originated over the intersection of 2 fissures, one running north and south parallel to the long axis of Kiushiu determining the long axis, and one at right angles determining the shorter axis and affording a line of activity along which a ridge of cones was later built.

ORIGIN OF THE BARRANCO

The single opening in the wall has been described as immediately opposite the western end of the central range. It may be that its origin is due to the line of weakness supposed to exist along the diameter occupied by this range, and that it was contemporaneous in origin with the caldera. Or it is possible that forces aided in the destruction of this point in the wall at the time that great eruptions were taking place along the central line and the new range was being built.

Another supposition is that it is a truncated canyon of the former Mount Aso, which has cut back and tapped the floor since the caldera was formed. There is not much evidence that the flanks of the former Mount Aso had become deeply dissected during the interval between its construction and its disappearance, and there is no other canyon making a comparably deep gap in the wall. Therefore the outlet

[1] *Popular Science Review*, New Series, Vol. IV, No. 16, October, 1880.

of the streams owes its origin more probably to one of the first-mentioned causes, or to the aid afforded by structural weakness to erosional work.

LIST OF LARGE CRATERS

A review of the literature on volcanoes reveals the fact that there are very many craters and volcanic depressions comparable with the Aso caldera in form and origin. The frequency of occurrence and importance of this type has not received adequate recognition in most of the textbooks. The following list gives the dimensions of some of the largest known craters, and of a few smaller ones that are typical calderas, out of the hundreds of large craters that might be cited. It is probable that the majority of these mentioned are volcanic sinks—have resulted, that is, from the subsidence of portions of volcanic mountains—and may therefore be termed calderas.

Monte Albano, in Italy, has a ring wall inclosing a crater 7 by 6 miles in dimensions.

Lago di Bolsena and Lago di Bracciano are crater lakes in Italy, the former measuring 8.5 by 7.5 miles, and the latter being round and with a diameter of 5.5 miles.

On Vesuvius, the old crater of Somma must have been nearly circular and 3 miles in diameter.

Val del Bove, on Mt. Aetna in Sicily, is a caldera 4 or 5 miles in diameter.[1]

Pantellaria, between Sicily and Africa, has traces of a crater ring 12 miles in diameter.[2]

Santorin, in the Mediterranean, is a volcanic ring 18 miles in circumference.

Palandökan, in Armenia, has a crater with long axis of 6 miles.[3]

Dyngufjöll, in Iceland, has a crater about 8 by 4 miles in dimensions with an area of 25 square miles.[4]

[1] Charles Lyell, *Principles of Geology*, 10th ed., Vol. I, p. 630.

[2] G. Poulett Scrope, *Volcanos*, 1872, p. 429.

[3] Hermann Abich, *Geol. Forschungen in den kaukasischen Ländern*, Theil II, Vienna, A. Hölder, 1878–87.

[4] Th. Thoroddsen, *Geog. Journ.* (London), Vol. XIII, Nos. 3 and 5, March and May, 1899.

Palma, in the Canary Islands, has a crater that has been reported as 9 miles in diameter.[1]

Teneriffe, in the same group, has a crater with longest diameter of 8 miles.[1]

St. Helena Island preserves the wreck of a crater which according to Darwin[2] may have measured 8 or 9 by 4 miles. From other descriptions the longest diameter does not appear to have been more than 4 or 5 miles.[3]

Mauritius according to Darwin has remnants of an oval crateral ring with shorter diameter of 13 miles.[2 and 4]

San Thiago (St. Jago) Island has a remnant resembling in character and size that of Mauritius.[2]

Réunion has a central, crater-like depression that is approximately round and 6 miles in diameter.[5]

Antandroy, in Madagascar, has a partially destroyed crater with diameter of 15 miles.[6]

In the District of Ngorongo, in East Africa, an apparently crateral depression measuring over 12 miles across has recently been described.[7]

Kamtschatka is said to contain a crateriform lake 15 miles in diameter surrounded by the Palan Mountains, and another large lake, called Kranosk, probably crateral.

Japanese lakes.—The following lakes of northern Japan may occupy calderas:

Tazawa, about 60 miles west of Morioka, Hondo. It is 6 miles in diameter, and the volcano Komago-take is within 10 miles of it.

[1] Leopold von Buch, *Physikalische Beschreibung der canarischen Inseln*, Berlin, 1825; also, *Ges. Schriften*, herausgeg. von Ewald, Roth und Dames, Vol. III, 1877, p. 150.

[2] Charles Darwin, *Geological Observations on Volcanic Islands*, London, Smith, Elder & Co., 1851, pp. 29–30.

[3] J. C. Meliss, *St. Helena*, London, L. Reeve & Co., 1875.

[4] M. Bailly, *Voyage aux Terres Australes*, tome I, p. 54.

[5] Charles Vélain, *Description Géologique de l'Ile de la Réunion, etc.*, Paris, Typographie A. Hennuyer, 1878.

[6] E. F. Gautier, *Madagascar*, Paris, Libraire Maritime et Coloniale, 1902.

[7] Fritz Jaeger, *Mitteilungen aus den deutschen Schutzgebieten*, Nos. 2 & 3, 1907. See also a review of this in the *Geog. Journ.* (London), Vol. XXX, 5, November, 1907, p. 560.

Towada, about 60 miles south of Aomori, Hondo. It is 10 miles in diameter and irregular.

Toya, near the coast north of Volcano Bay in Hokkaido. It is round and over 10 miles broad, and contains two islands. The volcano Usu-dake rises just south of it.

Shikots, over 60 miles south of Sapporo, Hokkaido. It is an irregular lake nearly 14 miles long and 7 broad surrounded by high mountains. There are volcanoes within 5 miles both northwest and southeast of it.

Kutcharo, over 50 miles south of the southernmost part of the north coast, in the northeast corner of Hokkaido. It is irregular, with approximate dimensions of 15 by 8 miles, and surrounded by mountains. A volcano and hot spring are just east of it.

Bombom, Luzon, is a rudely oval crater lake with mean diameter of 12 miles.[1]

Java[2] contains the following large craters: Ringguit, a remnant of a ring that may have had a diameter of 13 miles; Idien, a remnant with possible diameter of 10 miles; Hiiang, faint traces of an outer crater of 10 miles diameter; Tengguer, an entire summit crater over 5 miles across; there are also 3 other adjoining craters, and the 4 together seem to form a single elliptical depression measuring 7 by 5 miles; Ngadipouro, a remnant of a ring 6.5 in diameter; Tounggoul and related craters, 3 large rings that together seem to form a depression 15 miles long, and 12 miles wide at one end and 4 miles at the other; Danou, one remnant indicates a formerly existent ring 9 miles across, and 3 other rings together seem to form a crateral inclosure measuring 8 miles by 3; Prinsen-eiland between Java and Sumatra forms a partial ring 6.5 miles across; and the 4 islands of Parang, north of Java, make up a possibly crateral ring with diameter of 6 miles.

Maniendjoe and Singkarah are 2 lakes in Sumatra that probably

[1] Richard von Drasche, *Fragmente zu einer Geologie der Insel Luzon*, Vienna, Verlag von Karl Gerold's Sohn, 1878. Also, G. F. Becker, *Twenty-first Ann. Rept.*, U. S. Geol. Survey, 1899–1900, Pt. III.

[2] Franz Junghuhn, *Java;* German translation, Leipzig, Arnoldische Buchhandlung, 1857. Also, Verbeek and Fennema, *Description géologique de Java et Madoura*, Amsterdam, Joh. G. Stemler, 1896.

occupy crater basins; the greatest dimensions of the former are 14.5 by 7 miles, and of the latter 13 by 4.5 miles.[1]

Deception Island, in the South Shetland group, contains an oval crateriform harbor 6 miles long and 4 miles wide.

The well-known craters of the Hawaiian Islands are representative of the caldera type. The largest of them is Haleakala, which is of irregular shape and covers 16 square miles. It has 2 arms, each of which is about 6 miles long and 2 miles wide.[2] Mohokea caldera on the side of Mauna Loa measures about 6 by 5 miles.[3]

In Galapagos Islands there are 5 large craters on Albemarle Island. The largest is at the south end and has a length of about 12 and a width of about 6 miles. The others vary in size down to a length of 3 miles or less.[4]

The Central American lakes,[5] Atitlan and Amatitlan in Guatemala, and Ilopango in San Salvador, are 3 lakes whose origin was probably due to volcanic subsidence, although there is a difference of opinion regarding them. The first is 12.5 by 9 miles in greatest dimensions, the second, 9.5 by 3.5, and the third, 12.5 by 5 miles.

Masaya-Nindiri volcano, in Nicaragua, is surrounded by the remains of a crater that must have had a long diameter of 5 or 6 miles.[5, 6]

Crater Lake, in Oregon, occupies a deep caldera measuring 6 or more by 4.5 miles and having an area of 20.5 square miles.[7]

[1] R. D. M. Verbeek, *Topographische en Geologische Beschrijing Sumatra's Westkust*, Batavia, Landsdrukkerij, 1883.

[2] J. D. Dana, *Characteristics of Volcanoes*, New York, Dodd, Mead & Co., 1890. Also, Clarence Dutton, *Hawaiian Volcanoes*, Extract from 4th Ann. Rept., U. S. Geol. Survey, 1882–83, pp. 126–28.

[3] C. H. Hitchcock, *Bull. Geol. Soc. Am.*, Vol. CXII, October, 1906, pp. 485–96.

[4] This information was kindly furnished by Mr. W. H. Ochsner, of Stanford University and the California Academy of Sciences, who recently returned from a geological trip to these islands.

[5] E. G. Squier, *The States of Central America, etc.*, New York, Harper & Bros., 1858. Also, A. Dollfuss and E. de Montserrat, *Voyage géologique dans les républiques de Guatemala et de Salvador*, Paris, Imprimerie Impériale, 1868.

[6] Karl von Seebach, *Ueber Vulkane Centralamerikas;* aus den 38sten Bande der *Abhandlungen der Königlichen Gesellschaft der Wissenschaften zu Göttingen*, Dieterich-sche Verlags-Buchhandlung, 1892.

[7] J. S. Diller, *Professional Paper, No.* 3, U. S. Geol. Survey, 1902.

SUMMARY

The caldera of Aso is a great depression at the summit of a low mound-shaped cone in the center of the island Kiushiu, within 22 to 35 miles of the sea and only 1,000 to 3,000 feet above it. It has been the center of vast outpourings of lava and fragmental material that have filled a depressed area in the topography of the older formations during Quaternary time. It is one of the largest, if not the largest, of craters known on the earth.

The caldera has been worn considerably, but the wall has not been removed by erosion at any point, the single barranco being considered as due chiefly to structural weakness or subsequent disruption. The floor has been built up as well as worn down and probably retains fairly well its original level. The caldera appears to date from about middle Quaternary time.

In the history of the volcano both effusive and explosive eruptions have been characteristic, and have occurred contemporaneously, the amount of material emitted as lava flows having probably been greater.

The lava is intermediate between andesite and basalt, and is of comparatively easy fusibility.

There existed formerly a volcanic cone above the site of the present caldera, of which the truncated base is preserved in the outer slopes. The caldera grew as a result of the discharge of great lava flows and the collapse of this cone. The process was probably one of gradual enlargement of a summit crater.

A high, continuous interior range was later built up by eruptions along a fissure at right angles to the long axis of the caldera; and the cone building still continues, though with diminishing vigor, in a modern crater centrally situated with respect to the old one.